CONFIDENTIAL REPORT

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DEVELOPMENT, BUILDING AND UTILISATION OF A BLACK WATER TREATMENT UNIT AT DUMONT D'URVILLE AND CONCORDIA

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TECHNICAL NOTE 82.2

Concept engineering

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1 Introduction

The basic concept engineering of the black water treatment units of Concordia and Dumont d'Urville bases is proposed in this note. The bases are actually under construction and the approach for the treatment of the waste generated by the crew will be useful since both bases are inaccessible during the winter. Thanks to the biological systems proposed, which will aim to degrade the waste and produce beneficial energy, mainly in the form of methane and CO_2, the transportation of the waste will not be necessary.

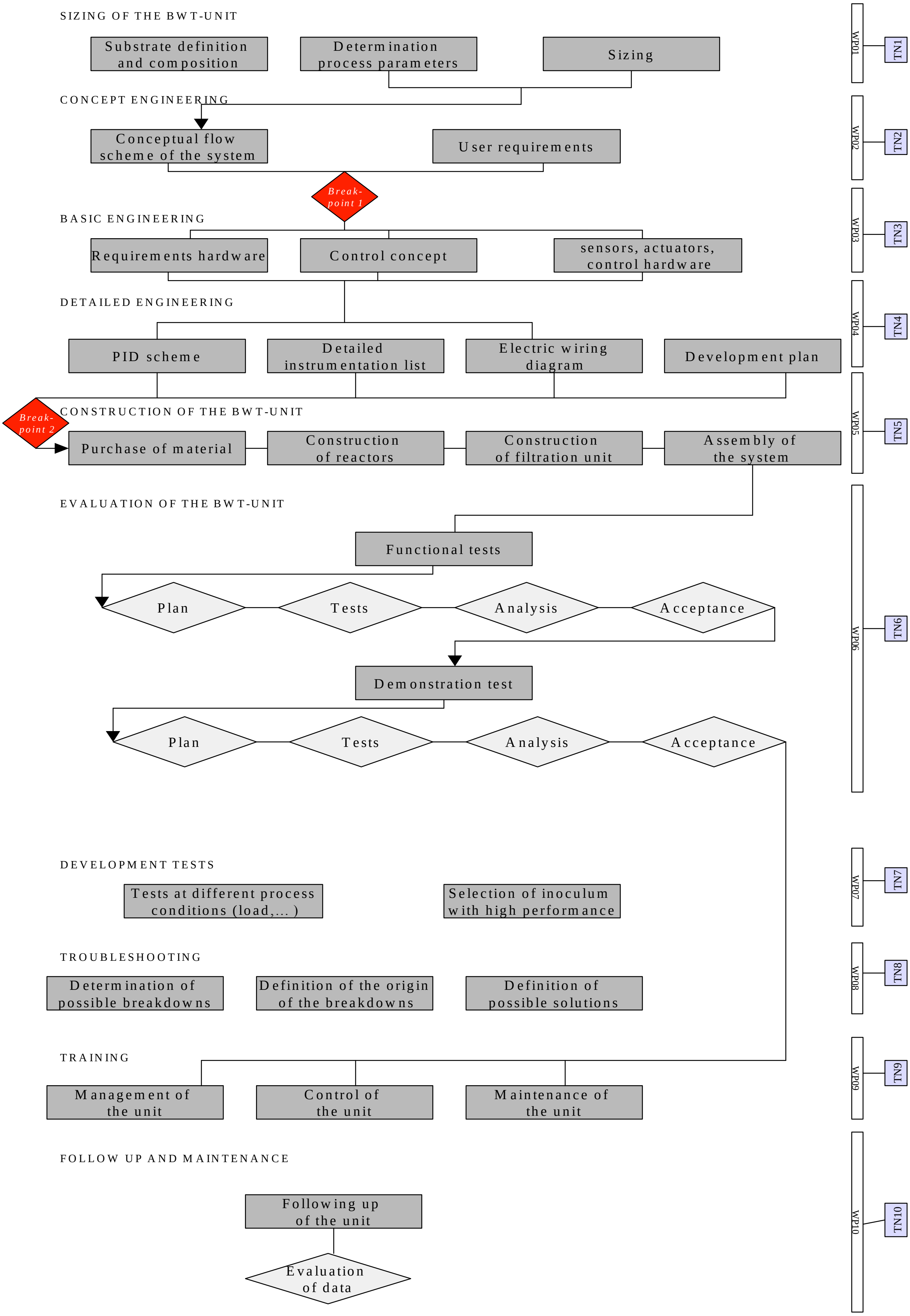
The permanent base called Concordia is to be opened in the centre of Antarctic continent by the year 2003. There, a black water treatment unit will be elaborated to treat the waste produced by 15-16 persons for 365 days. The black water treatment unit will have to ensure satisfactory functioning when the load is 5 times higher than the load engendered by 15 persons. Indeed, during the period of 365 days (12 months), the station will be manned with 35 more persons for 90 days and another 20 persons for 30 days. The waste will consist of faecal material, urine, toilet paper, kitchen rest and the rest from the dining room. In addition to this waste, the concentrate originated from the treatment of the grey water will be included. The grey water treatment facilities are carried out by Technomembranes in collaboration with IPEV and ESA. The treatment of grey water consists mainly of membrane filtration (ultra- and nanofiltration) and reverse osmosis. The collected concentrate from the ultrafiltration and nanofiltration steps will have to be treated by the black water treatment unit.

Dumont-d'Urville base can be divided into two residences: the winter residence and the summer residence. The Dumont-d'Urville summer base can be inhabited by 25 people of the Dumont d'Urville winter base during 125 days a year and will be used as a place to sleep only. The remaining days, the people will stay in Dumont d'Urville winter base, since the summer base will not be accessible. The BWT-unit will have to treat human excrements (urine and faecal material only).

Based on this number of persons and the specificity of the infrastructure at Dumont d'Urville and Concordia stations, the sizing of the units will be elaborated. This includes the definition of the amount of waste, which will have to be treated and also the amount of water that is discharged to the treatment facilities. The final effluent generated by the black water treatment unit will be further processed in the grey water treatment unit (designed by technomembranes and constructed by Polymem), why the necessity to define its composition and daily generated volumes.

2 Objectives

The work plan, as proposed initially, for the elaboration of the BWT-units for Concordia as well as for Dumont d'Urville stations can be summarised as follows:


SIZING OF THE BWT-UNIT
Substrate definition and composition
Determination process parameters
Sizing
CONCEPT ENGINEERING
Conceptual flow scheme of the system
User requirements
Break-point 1
BASIC ENGINEERING
Requirements hardware
Control concept
sensors, actuators, control hardware
DETAILED ENGINEERING
PID scheme
Detailed instrumentation list
Electric wiring diagram
Development plan
Break-point 2
CONSTRUCTION OF THE BWT-UNIT
Purchase of material
Construction of reactors
Construction of filtration unit
Assembly of the system
EVALUATION OF THE BWT-UNIT
Functional tests
Plan
Tests
Analysis
Acceptance
Demonstration test
Plan
Tests
Analysis
Acceptance
DEVELOPMENT TESTS
Tests at different process conditions (load,...)
Selection of inoculum with high performance
TROUBLESHOOTING
Determination of possible breakdowns
Definition of the origin of the breakdowns
Definition of possible solutions
TRAINING
Management of the unit
Control of the unit
Maintenance of the unit
FOLLOW UP AND MAINTENANCE
Following up of the unit
Evaluation of data
WP01
TN1
WP02
TN2
WP03
TN3
WP04
TN4
WP05
TN5
WP06
TN6
WP07
TN7
WP08
TN8
WP09
TN9
WP10
TN10

The main objectives of this work package (WP 2) are:

- Optimal configuration of the bioreactors and the separation units of the Concordia unit.
- Listing of the necessary sensors, actuators and control hardware
- Concept engineering of the units based on the user requirements (IPEV) including operation, automation level, safety aspects and monitoring.

A conceptual scheme is aimed to be delivered at this phase of the work and after acceptance of the scheme by the project partners, a more detailed phase will be investigated dealing with the basic and detailed engineering of the black water treatment unit.

3 Reactors configuration

3.1 System limitations and general configuration

As already mentioned in TN80.1, the configuration of the black water treatment units depends on some important process parameters and limited by some constraints as shown in Figure 1.

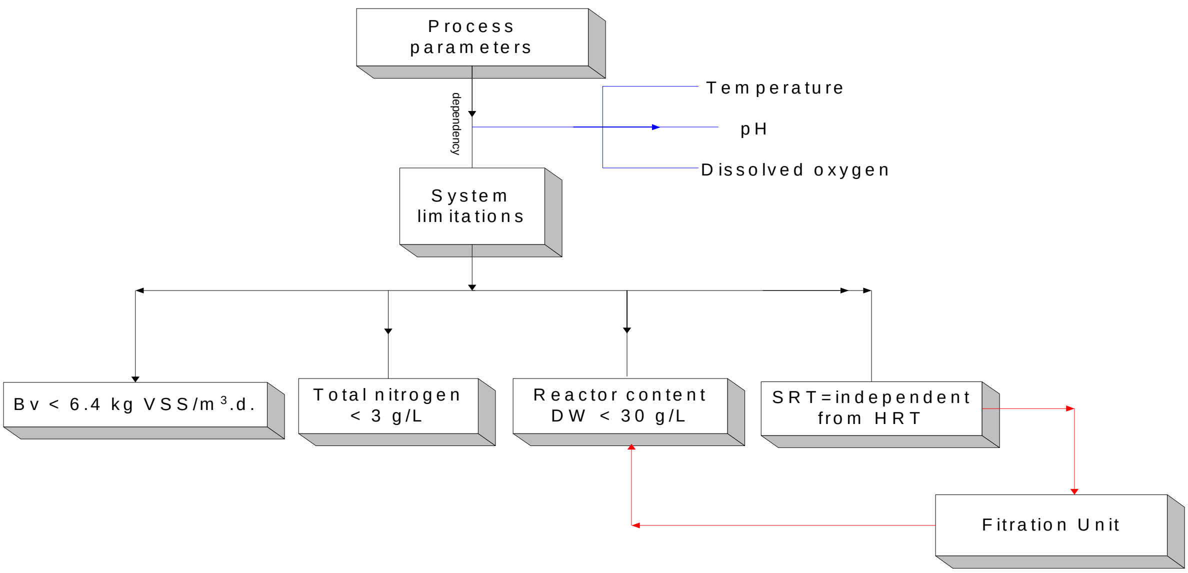


Figure 1.Process parameters and limitation factors of the system

The general concept of the BWT-Unit as initially proposed is presented in Figure 2. In this note the specifications of the bioreactors and the concentration system are elaborated.

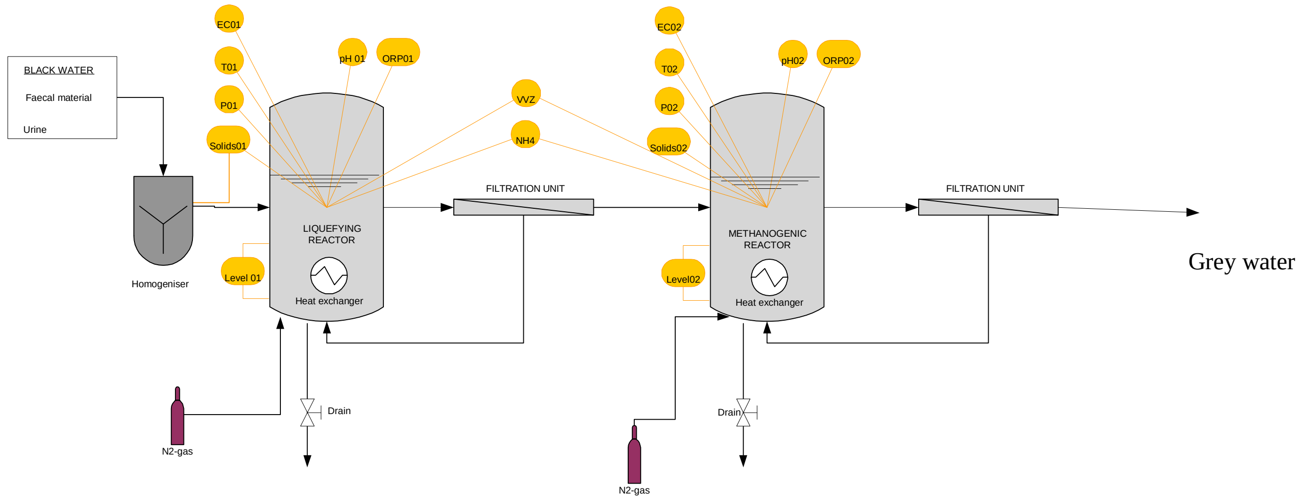


Figure 2. General concept of the BWT-Unit

3.2 Liquefying reactor

This reactor needs to be operated at 55°C (thermophilic conditions) and at a pH of 5.8 - 6 to avoid methane production. The pH will be controlled by addition of acid and base. The reactor will be operated in anaerobic conditions. The biodegradation efficiency of the reactor needs to be at least 55%. The reactor needs to be provided with several interfaces among which the solid loop with the waste material and the filtration unit. The latter will be equipped with an ultrafiltration membrane.

3.3 Filtration unit

The main aim of using a membrane ultra-filtration module (tubular membranes type) is to separate the liquid phase from the solid phase. In the present concept a membrane filtration unit is proposed to separate the liquid stream containing volatile fatty acids (VFA), nitrogen, COD soluble and salts from the insoluble fraction. The liquid stream will be fed to the methanogenic reactor, where the VFA and COD_s will be further converted exclusively, into methane and carbon dioxide. The solid fraction will be retained by the membrane filter and returned back to the acidifying reactor for further transformation reactions. Thus the biomass will be recycled and the Solid Residence Time (SRT) will be high enough to allow consequent reduction of the Hydraulic Residence Time (HRT).

In the proposed concept a low overpressure is needed to speed up the mass transfer process through the membrane. In general an overpressure of 0.5 to 2 bars will be applied to generate the required filtrate to be fed to the methanogenic reactor.

3.4 Methanogenic reactor

The methanogenic reactor treats the effluent of the liquefying reactor through the filtration unit. It needs to be operated at 55°C and in anaerobic conditions. Low pH is inhibiting the methanogenesis, therefore, a regulation with acid and base addition will be set up to maintain neutral pH. As for the liquefying reactor it is important to retain the sludge in the system. This is allowed by using a fixed bed reactor, from which the collected effluent is supposed to be exempt of solids and could eventually be directed towards the grey water unit without passing through a second filtration step. This possibility is being studied on lab scale reactors and if necessary, other steps will be added, depending on the quality and the colour of the effluent. The methanogenic reactor will produce biogas, which should be burnt either by using a flare or by using a generator. Based on the estimation of the biogas production, the options for future of methane will be studied. Given the low average production no recovery of energy will be realised when treating the methane.

4 Definition of user requirements

The user requirements will be taken into account in the concept of the unit, regarding the treatment efficiency, operation, automation, safety and monitoring aspects.

4.1 Substrate definition

The Concordia BWT-unit is aimed to degrade the following substrates:

- Faecal material
- Urine
- Toilet paper
- Kitchen wastes
- Concentrate from grey water treatment

The BWT-Unit of the Concordia base will have to treat the faecal material, toilet paper, urine and waste food including kitchen rest generated by 15 and 70 persons during 365 days (12 months). The unit should also treat the concentrate from ultrafiltration and nanofiltration steps included in the treatment of the grey water designed and developed by Technomembranes (Fr).

According to IPEV, a volume of 10L is used per person and per day for the toilet flush. In this volume, 1.5 L urine, 0.09 L faecal material, 18g toilet paper (data generated from EWC reports in the framework of MELISSA-project) and 463 g fresh kitchen waste generated by one person will be diluted. This consists of a total volume of ± 1.6 L/d produced by one person to be treated in the BWT-unit diluted in 10 L water. On this influent the concentrates UF and NF from the grey water system will be added, with a volume of 10.4 L per person and per day. Table 1 gives an overview of the loads and flows generated by the Concordia inhabitants and which will have to be treated by the black water treatment unit.

Table 1. Feed composition of the BWT-unit of Concordia

	Toilet flush	**Toilet paper (DW)**	**Urine (DW)**	**Faecal material (DW)**	**Food waste (DW)**	**Food waste (FW*)**	**Grey water (COD)**
Load (g/person.d)	0	18	51	30	35	463	68- 182
Flow (L/person.d)	10	0	1.5	0.09	-	4	10.4
Load (g/15persons.d)	0	270	765	450	527	6945	1020 - 2730
Flow (L/.d)	150	0	22.5	1.35	-	60	156
Load (g/70persons.d)	0	1260	3570	2100	2500	32410	4760 - 12740
Flow (L/d)	700	0	105	6.3	-	280	728

FW: Fresh weight

As specified by IPEV, the faecal material, urine and toilet paper are collected from toilets using a suction – vacuum system; these toilets are flushed with an average volume of 10 litres of water per person and per day. The kitchen wastes will be first grinded with a food waste disposer, In-Sink-Erator®, present at IPEV location, into fine particles of around 4 to a maximum of 5 mm. Both wastes will be collected and mixed together, with the concentrates from UF/NF of GWT-Unit, in a buffer tank which will be designed and constructed by EPAS before being introduced into the liquefying reactor. The size of the particles could be reduced to around 1 to 2 mm by installing a second grinding device or a pre-filter between the buffer tank and the liquefying reactor. By this mean, premature clogging of the ultrafiltration membranes can be avoided. At this stage of the study, no specific type grinder or pre-filter were selected. It was however thought to test some types of fine grinding devices like: type MONSTER® during the test period of the BWT-Unit at EPAS and to evaluate its capacities.

4.2 Unit size

A special container was first planned to include both the black and the grey water treatment units. However, given the requirements of the units, IPEV will provide an adapted container dedicated to the Black Water Treatment unit. The dimensions will be calculated and proposed in TN80.3.

4.3 Hardware selection

The hardware selection should be as much as possible harmonised between EPAS and Technomembranes. This step of hardware selection will be developed in more details in TN80.4. Since the BWT-Unit will be used as a validation test of the MELISSA-loop mainly the liquefying reactor, material selection will also have to be harmonised as much as possible with the one selected for the waste compartment of the MELiSSA loop. Connections and some other instrumentation not directly related to the EWC will have to be harmonised with the material of the GWTU.

4.4 Automation

The automation is wanted to be as much as possible minimised (level 0 to level 1) in a first instance, in order to enable a mechanical control, on request of the final user. Nevertheless, as future steps including test of control laws proposed by ESA are expected, the upgrading of the automation level to level 1 and eventually to level 2 has to be foreseen.

4.5 Safety aspects

On request of IPEV managers, and due to the important psychological and operational risks in site, the decision was taken to consider a colour treatment unit of the BWTU effluent. The latter has to be as clear as possible Practical tests will be performed in order to choose an appropriate method (UV oxidation, peroxide, ozone, Activated carbon…). For this purpose, an extra step for the removal of colour from the effluent will be studied to be added at the end of the system. Different possible technologies will be proposed and the most realistic technology giving the best results will be selected.

Screening of pathogens in the final effluent will also be followed via the use of microbiological tests for the identification and enumeration of faecal Coliforms, E-coli , Enterobacteria and Streptococcus. Microbiological techniques based on plating small amounts (few millilitres) of the effluent in general and selective media and incubation at specific temperatures for defined time, will allow to have a qualitative and quantitative microbiological evaluation of the effluent generated from the BWT-Unit. More detailed data about the growth media and the results related to the screening of potential pathogens in the effluent will be presented in TN 82.7.

4.6 Monitoring

Due to the low level of automation that is wanted in a first phase, a minimum of parameters should be followed with on-line sensors. Nevertheless, critical parameters like: pressures, volumes, liquid and gas flows, temperature, pH,… have to be PC-PLC regulated where the need to at least level 1 control strategy. It is important that the level of automation To close the gas balance, an on-line gas analyser would be advisable to use. The corresponding data (on-line and off-line) recorded by means of a remote and monitoring supervision system (RMS) will be regularly transmitted using Internet facilities to EPAS who will perform a parallel follow up of the data together with BWT-unit responsible of IPEV.

5 Operation of the unit

5.1 Feeding of the liquefying reactor

The influent will be collected from the food waste disposer and the toilets in a buffer stirred tank of 2400 litres provided by IPEV. It will be pumped into a second stirred collection tank of 2000 litres to control the liquid level in the liquefying reactor. The mixed and stirred influent will be fed in a continuous mode to the liquefying reactor. The first buffer tank will be by this means filled-up and emptied depending on the daily load and the waste discharged without disturbing the process The liquid levels have to be controlled in both tanks, the collection tank and the reactor. Given the variability of the waste amount (related to the variability of the base occupation), the elaborated strategy to control the volume in the liquefying reactor and the buffer tank will consist of differential pressure level sensors installed in both sides (buffer tank and liquefying reactor) and a level switch . The type of material that was selected will be presented in TN 82.3.

5.2 Operation of the liquefying reactor and filtration unit

The liquefying reactor activity will be controlled by regulating the pH, pressure, temperature and Total Suspended Solids (TSS). The pH will be regulated by addition of acid or base. Acid dosage will be in the form of HCl or organic acid (Citric acid). To avoid increase in the electroconductivity in the liquefying reactor due to HCl dosage, citric acid would be preferable. Base dosage will be necessary during the start-up of the liquefying reactor for pH stabilisation. It will be in the form of NaOH. The frequencies for acid or base additions will be studied on the lab-scale reactors and the obtained results extrapolated on the BWT-Unit. The results on lab-scale reactors and the calculations for dosage frequencies on the BWT-Unit will be presented in TN 82.7.

A connection to drain part of the reactor content will be installed in case of necessity (TSS > 4.5%, renewal of the inoculum due to acute toxicity,…) The frequency of drain will be determined during the follow-up of the laboratory reactor. The reactor content will circulate using a pump through the membrane filtration unit. The solids will go back to the reactor and the filtrate will be fed to the second reactor. A storage tank containing cleaning and rinsing agent will be connected to the filtration unit to allow its cleaning. A certain pressure (not exceeding 2 bar) will be applied on the system, allowing the transfer of the soluble matter. The filtration unit will run continuously. The amount of filtrate sent to the second reactor will be regulated with a master pump which is aimed to deliver only the necessary flow to the methanogenic reactor. By this mean, a fixed flux will be applied avoiding thus rapid fouling of the membranes. In normal operation, ultrafiltration membranes can become fouled depending on the applied flux. Indeed, the higher the flux, the much faster the clogging inside the membrane matrix (Fan et al., 2000) . The deposits build up during operation and cause loss in filtrate output. Elements should be cleaned whenever the normalized water output rate drops by 15% from its initial flow rate (the flow rate established during the first 24 to 48 hours of operation). It should be noted that the filtrate output rate will drop if feed waste temperature decreases (Wilf and Alt, 2000). This is normal and does not indicate membrane fouling.

PVDF-type membranes were selected as potential candidates to be used in the BWT-Unit based on the satisfactory preliminary results obtained on the filtration unit of the waste compartment in the MELiSSA-project (tests performed on the EWC-prototype reactor at EPAS) . It is important to mention that the technology that is wanted to be used in the framework of the BWT-Unit project has as main objective the validation of the technologies selected in the MELiSSA-project.

5.2.1 Cleaning of the filtration membrane

Different cleaning agents could be used for the clean-up of the filtration module. Here, the most widely used cleaning procedure is proposed, which shows satisfactory re-establishment of the initial water flux rate through the membrane. The cleaning procedure is exclusive for Polyvinyldine Difluoride (PVDF) organic membranes from X-flow and can not applied to other type of membranes.

5.2.1.1 Cleaning procedure

According to the supplier of the organic PVDF membranes, the cleaning procedure can be completed in about 1 hour. Most cleaning chemicals used are common and inexpensive. For an efficient cleaning, the chemical solutions have to be at 54°C. Acid treatment was found to be quite effective in restoring the original flux rate. It alters the chemical characteristics of particles within the pores to facilitate their removal during the subsequent caustic wash. This caustic wash is followed by treatment with an oxidant to remove caustic residues while also disinfecting the equipment. Removal of all residues of the cleaning agents is mandatory. They must be recuperated in an apart tank and not re-introduced into the system to avoid possible irreversible inactivation of the microorganisms and thus decrease in the biodegradation efficiency . It The cleaning procedure consists of:

1. Acid Cleaning
A mixture of nitric and phosphoric acids (1/1) at pH 2 is recirculated for 20 minutes through the filtration module

2. Flushing with tape water
It allows rinsing of the module for 2 minutes.

3. Alkaline Cleaning
Sodium hydroxide at pH 11, with 200 ppm sodium hypochlorite is recirculated for 20 minutes.

4. Flushing with tape water
It allows rinsing the whole filtration module in site.

5. Sanitizing
For this purpose, 100 ppm of hypochlorite or 100 ppm of dichloroisocyanurate can be used. According to Bohner and Bradley, 1992, the use of these reagents results in membranes free from viable microbial populations.

6. Flushing and keeping merged in water
It allows keeping the ultrafiltration module in solution until re-use to avoid drying of the membranes.
Caution: The filtration module has to be thoroughly flushed with water before another cleaner is used. Cleaning chemicals may react with one another or fouling products to produce additional fouling on the membrane.

Whether the system needs acid or alkaline, cleaning will depend on the type of fouling material suspected. It is recommended to perform acid cleaning first even when alkaline cleaning is desired. If system performance recovers with acid cleaning, then alkaline cleaning is not necessary.

5.2.1.2 Cleaning system

Cleaning of the filtration membranes will be done by connecting the cleaning tank and pump system to the membrane system. It may be necessary to clean one tube at a time depending on the flow requirements. Pump pressure must not exceed 30 psi (2 bar). Permeate and concentrate lines must return to the cleaning tank to avoid introduction of the cleaning agents into the system. Therefore, it would be necessary to fill the tank at the end of the cleaning with water, to flush for 10 to 15 minutes and to add clean water as necessary until the clean water pH is almost the same as the concentrate pH. The possibility of recovery, re-use and/or storing of the rinsing chemicals is actually under investigation at EPAS laboratory.

5.2.1.3 Frequency of membrane renewal

The replacement of the filtration membranes depends on the type material that is responsible for the clogging. Inorganic particulates can be easily removed from the membrane by cleaning the latter with the above-cited chemicals. Some organic compounds may induce irreversible clogging of the pores of the membranes (oil, fats, colloids…). In this case, the membranes have to be renewed rather than cleaned. Therefore, it is necessary to test the membrane filtration system of the Black Water Treatment Unit at laboratory scale to determine the period at which the membranes have to be replaced. From preliminary data obtained with the lab scale reactors, the PVDF organic membrane has to be replaced each 3 months. To verify this estimation, functional tests on the full BWT-Unit, during its operation will be performed and a better evaluation of the membranes lifetime will be established. Here again different types of substrates (oil, cheese breeds, fats and insoluble particles) will be tested on the unit. Nevertheless, the possibility to use another type of membranes like inorganic membranes "ceramics" will be investigated since the latter can undergo high resistance towards chemical cleaning and seem to have higher life time.
Membrane selection will also be based on the output of the studies conducted on the ultrafiltration unit of the EWC-project. Depending on the obtained results, it will be concluded about the choice of the type UF-membranes for the BWT-Unit.

5.3 Operation of the methanogenic reactor

In the second methanogenic reactor, pressure, pH, temperature will be measured. The pH will also be controlled by addition of acid or base.
The gas phases of both reactors (liquefying and methanogenic) will be connected to a gas loop equipped with pressure regulators.

The methanogenic reactor will be an up-flow fixed bed reactor. Carrier material type amorphous catalyst DAVICAT® SP 550-10046 from DAVISON *Catalysts* is actually being tested on lab scale reactor. The biomass will be fixed in the carrier material to avoid washout and maintain subsequent sludge retention time in the reactor.

To comply with psychological thinking of the Black Water Unit users, a complementary step will be added to the whole system to remove the unwanted colour from the effluent. Therefore, different techniques are being tested (UV, Peroxide, Ozone, GAC…). According to preliminary tests performed in batch experiments, Granular Activated Carbon gives to best results and therefore, is actually added in a column at the outlet of the effluent. The biomass, if any, will escape from the reactor; it will be captured in the activated carbon particles. The results of these investigations (COD removal, colour removal, …) will be presented in TN 82.7.

6 Concept for unit configuration

The concept of the BWT-unit including the liquefying reactor, the UF-unit and the methanogenic reactor for Concordia base is presented in Figure 3.

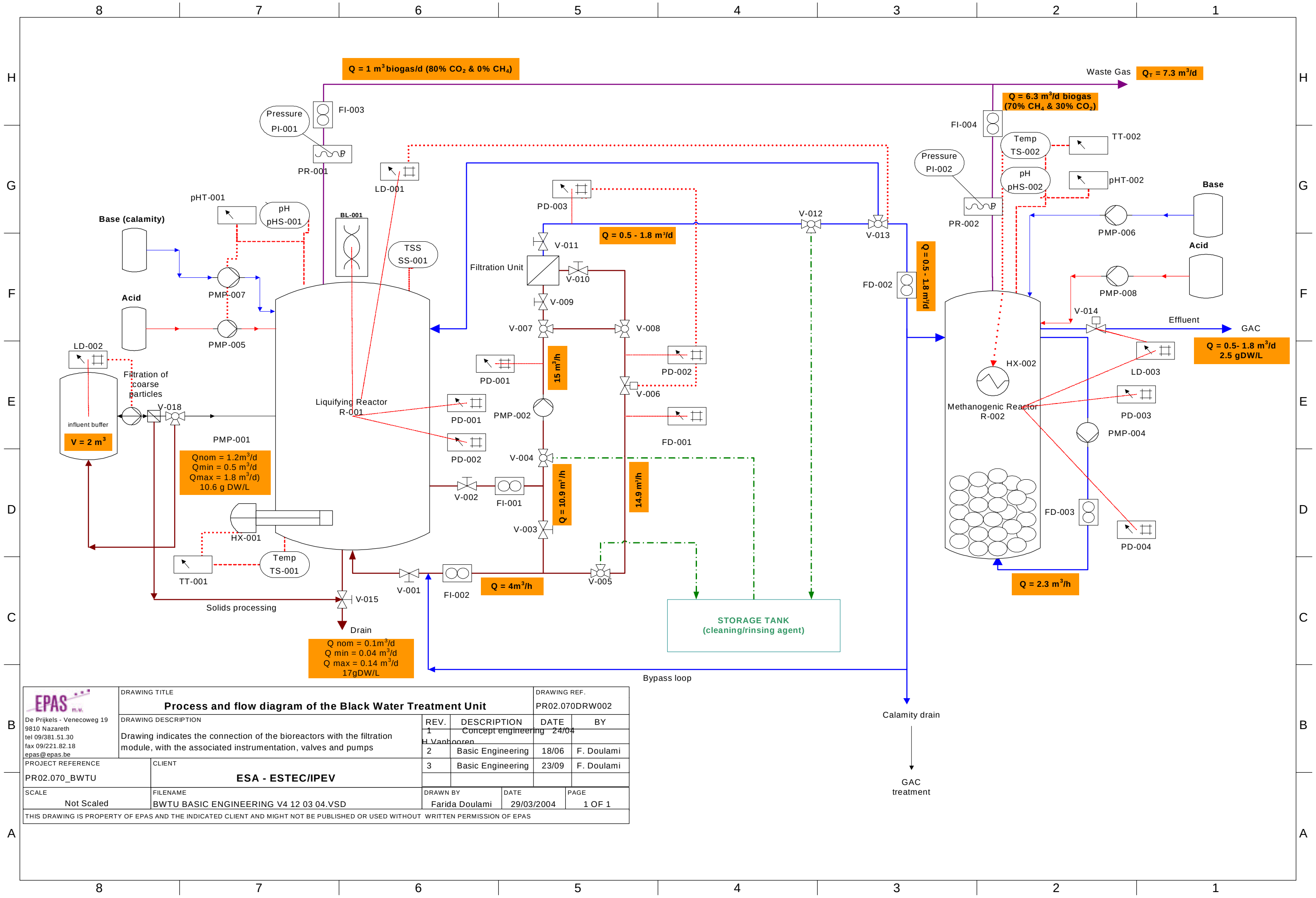


Figure 3. Concept engineering flow scheme of the BWT-Unit

7 List of necessary sensors and actuators

The necessary equipment figuring on the concept scheme are listed in the following table (Table 2). A final overview of all selected instrumentation is given in TN 82.3. For safety reasons, some sensors will be installed in double like the pH and temperature sensors. This safety is necessary to allow satisfactory functioning of the biological treatment and avoid drastic changes in pH and/or temperature in the reactors.

Table 2. General equipment of the BWT unit

Tag	Description	Type
R-001	Liquefying reactor	Anaerobic tank
R-002	Methanogenic reactor	Upflow fixed bed reactor
BL-R-001	Blender for liquefying reactor	
Filtration Unit	Liquid solid separation system	Capillary ultrafiltration module
FD-001	Regulates the liquid flow through the filtration unit	Flow transducer
FI-001	Indicates the liquid flow from the liquefying reactor to the filtration unit	Rotameter
FI-002	Indicates the liquid flow from the filtration unit to the liquefying reactor	Rotameter
HX-001	Heating system of liquefying reactor	
HX-002	Heating system of methanogenic reactor	
LD-001	Controls the liquid level in liquefying reactor	Level Switch
LD-002	Controls the liquid level in influent buffer tank	Level Switch
LD-003	Controls the liquid level in methanogenic reactor	Level Switch
PD-001	Measures the pressure at the inlet of the filtration unit	Pressure transducer
PD-002	Measures the pressure in the retentate	Pressure transducer
PD-003	Measures the pressure in the filtrate	Pressure transducer
pHS-001	Measures the pH in liquefying reactor	pH sensor
pHS-002	Measures the pH in methanogenic reactor	pH sensor
pHT-001	Regulates the pH in liquefying reactor	pH transmitter/controller
pHT-002	Regulates the pH in methanogenic reactor	pH transmitter/controller
PI-001	Indicates the gas pressure at the outlet of liquefying reactor	Manometer
PI-002	Indicates the gas pressure at the outlet of methanogenic reactor	Manometer
PMP-001	Influent pump	Progressive cavity pump
PMP-002	Pump sending effluent liquefying reactor to filtration unit	Progressive cavity pump
PMP-003	Pump feeding the methanogenic reactor with filtrate	Progressive cavity pump
PMP-004	Recirculation pump in methanogenic reactor	Progressive cavity pump
PMP-005	Acid dosage pump for pH regulation in liquefying reactor at pH 6	Pulse pump

PMP-006	Base dosage pump for pH regulation in methanogenic reactor at pH 7-7,5	Pulse pump
PMP-007	Base dosage pump for pH regulation in liquefying reactor at 6	Pulse pump
PMP-008	Acid dosage pump for pH regulation in methanogenic reactor at 7-7,5	Pulse pump
PR-001	Diaphragm-sensed backpressure regulator: regulates pressure in liquefying reactor, relieves net gas produced	Backpressure regulator
PR-002	Diaphragm-sensed backpressure regulator: regulates pressure in methanogenic reactor, relieves net gas produced	Backpressure regulator
R-001	Liquefying reactor	Double jacket anaerobic tank
R-002	Methanogenic reactor	Upflow fixed bed reactor
TS-001	Measures the temperature inside liquefying reactor	Thermocouple
TS-002	Measures the temperature inside methanogenic reactor	Thermocouple
TT-001	Regulates the temperature in the liquefying reactor	Temperature transmitter/controller
TT-002	Regulates the temperature in the methanogenic reactor	Temperature transmitter/controller
V-001	allows to disconnect liquefying reactor from the whole system if necessary	Two-way ball valve
V-002	allows to control the recircultation over the filtration unit	Butterfly valve
V-003	allows to control the recirculation over the filtration unit	Butterfly valve
V-004	input for cleaning/rinsing agent towards filtration unit	Three-way ball valve
V-005	output for cleaning/rinsing agent towards filtration unit	Three-way ball valve
V-006	Transmembrane controlling valve for the production of filtrate	Controlled two-way valve
V-007	allows to bypass the filtration unit at start-up	Three-way ball valve
V-008	allows to bypass the filtration unit at start-up	Three-way ball valve
V-009	allows to disconnect filtration unit if necessary	Two-way ball valve
V-010	allows to disconnect filtration unit if necessary	Two-way ball valve
V-011	allows to disconnect filtration unit if necessary	Two-way ball valve
V-012	output for cleaning/rinsing agent towards filtration unit	Three-way ball valve
V-013	regulates the filtrate stream towards the methanogenic reactor or back to liquefying reactor	Three-way ball valve
V-014	Controlled valve for effluent production	Controlled two-way valve
V-015	Drain of the liquefying reactor	Two-way ball valve

8 Conclusion and future work

The next steps will include the basic and detailed engineering of the unit, and the continuation of experimental lab-scale tests.

9 References

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